"NEW" CANDIDATES FOR ULTRASONIC
NDE STANDARDS AND CALIBRATIONS

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ABSTRACT

The National Bureau of Standards program in acoustic-ultrasonic calibrations and standards, aimed at solving some of the immediate problems, is reviewed. Work on acoustic emission transducers is directed at the determination of sensitivity and spectral response by the use of a reproducible stress impulse. Also in the area of acoustic emission is a program to develop a theoretical basis for acoustic emission signal analysis to characterize moving cracks or defects. Work on the characterization of ultrasonic transducers which should lead to formal calibration services in the near future includes determination of spectral characteristics by measuring the pressure of the ultrasonic radiation field, determination of the radiation pattern from near field measurements and total power by calorimetry. Although the current NBS program is oriented toward standards and calibrations, instrumentation problems are being addressed including the improvement of signal-to-noise ratio by methods such as pulse compression and signal averaging, and the characterization of the important variables in ultrasonic instrumentation. The reliability of flat-bottom hole aluminum reference blocks, which are in wide use, has been improved and a calibration service is now available. Further directions for this effort will include calibration services for steel and titanium blocks, the development of material independent blocks and the development of well-characterized fatigue cracks that could provide calibration for many NDE tests. The use of theoretically characterized scattering from spheres as a standard has recently come into prominence, and Rockwell and NBS have begun to explore this possibility. However, many other standards and calibration procedures for ultrasonic NDE have been proposed or are in use. To provide a fresh look at this area, particularly as it applies to DoD systems, NBS has initiated a program funded by ARPA to assess the status of the field, determine current and future needs, and propose a plan for realizing these needs.

Introduction

A program in nondestructive evaluation (NDE) was formalized in 1975 at the National Bureau of Standards, although various segments of the program had been in existence prior to then. This program, coordinated by the Institute for Materials Research, is aimed at assisting industry and government agencies to make effective use of NDE by improving its reliability and making it more quantitative through standardized NDE measurement procedures. This includes the improvement and development of standards and calibrations, procedural documents such as recommended practices, characterization of instruments, development of improved techniques, and the assessment of the NDE measurement on material performance. Current emphasis in the program is on acoustic emission, ultrasonic measurements, x-ray and neutron radiography, electromagnetic methods (eddy current, visual inspection, microwave methods), penetrant testing, wear debris analysis and thermal testing.[1]

This paper discusses the NBS program in acoustic-ultrasonic standards and calibrations. Certain elements of this program were initiated with medical applications in mind while others address some current standards and calibrations problems in NDE. Since ultrasonic NDE depends so vitally on transducer performance, much effort has been devoted to its characterization, and a formal calibration service is planned in the near future. Transducer characterization includes determination of spectral characteristics by measuring the pressure of the radiation field, determination of the entire radiation pattern from near field measurements, and measurements of the total radiated power by calorimetry and an electrical method. Work on acoustic emission transducers is directed at the determination of sensitivity and spectral response by the use of a reproducible stress impulse. The reliability of flat-bottom hole aluminum reference blocks has been improved to the point where a calibration service has been established.

In addition to the work discussed here, many other standards and calibration procedures for ultrasonic NDE have been initiated or are in use.[2-4] To provide a fresh look at this area, particularly as it applies to DoD systems, NBS has proposed a program partly funded by ARPA[5] to assess the status of the field, determine current and future needs for standards and calibrations, and propose a plan for realizing these needs.

Calibration of Ultrasonic Transducers

This section deals with various techniques which have been developed for characterizing ultrasonic transducers.

Ultrasonic Calorimeter[6]

Calorimetric equipment, schematically shown in Fig. 1, was designed to measure ultrasonic beam power from 1 mW to 10 W, at frequencies from 1 to 15 MHz with uncertainties less than ± (7% + 0.2 mW).

The equipment will accommodate ultrasonic beams having diameters as large as 26 mm, sufficient for a wide variety of medical diagnostic and therapeutic transducers, and for many transducers used for NDE. Twin vessels are provided so that the temperature rise due to the ultrasonic energy absorbed in one vessel can be compared rapidly with accurately measured dc electrical power supplied to a heater in the other vessel. Liquid, whose temperature is equalized by a heat exchanger, enters each vessel near the input port. Twin temperature sensors, located in the output flow from the vessels, are connected to an electrical bridge circuit. The advantage of a twin series-flow calorimetric method is a decreased need for accurately controlling the flowrate and temperature rise. In addition, ambient temperature effects are minimized and insulation requirements are not stringent as in single flow systems. By using a solid as the principal absorber and a liquid to transfer the heat to the sensor, the vessel size, the effective volume of the liquid and the effective volume-displacement time could all be reduced.

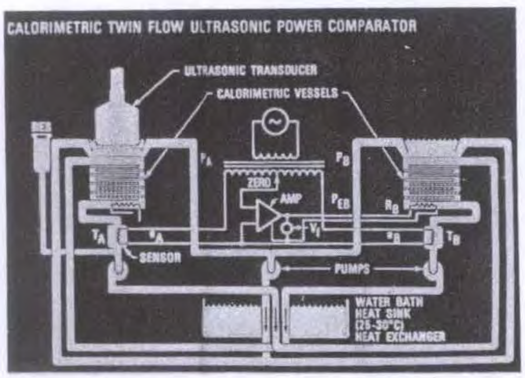

Figure 1. Calorimetric twin flow ultrasonic power comparator.

Power Output by Modulated Radiation Pressure[7]

The spectral characteristics of transducers are determined by measuring the pressure of the radiation field. In this method the input to the transducer is modulated at a low frequency (~39 Hz) and the total output power is intercepted by an absorbing target which experiences a force at the modulating frequency. For a perfectly absorbing target in a collimated beam, the total radiation force equals the incident power divided by the speed of sound in the medium. For propagation in water this force is roughly 67 mg per watt.

The target is mounted on the armature of an electromagnetic microphone provided with an independent coil through which a current at the modulating frequency is adjusted in amplitude and phase (manually or automatically by feedback) to arrest the motion of the armature. The force then depends only on the current, and the apparatus can be calibrated absolutely using direct currents and dead weights. The carrier frequency may be swept over any part of the range 1-80 MHz while a recording of power output versus frequency is made.

The apparatus is stable and easy to use, and the results are absolute. The sensitivity is very high, ~7μw; the uncertainty varies from 2 percent at 1 MHz to 12 percent at 30 MHz.

Transducer Calibration by an Electrical Method[8]

In this method of calibrating specially designed half-wave resonant, air-backed, quartz piston transducers, a highly accurate twin-T null circuit is employed for the measurement of its electrical conductances under certain loading conditions. This permits calculation of the equivalent resonant radiation conductance, which when multiplied by the square of the applied voltage, yields the emitted ultrasonic power into a load. A wide range of accurately known ultrasonic beam power levels (±5 percent in the range from 1 to 5 MHz) can be obtained by quartz transducers, which thus characterized, can be used for calibrating or checking ultrasonic power measuring equipment.

Measurement of Beam Profiles[9]

Apparatus has been developed for determining the planar distribution of voltage amplitude and phase of ultrasonic transducers. Experimental results are shown in Fig. 2. Given a known receiving probe, this work shows that a single planar scan in the near field of a moderately directive radiator is sufficient to provide relative distributions of quantities such as pressure, particle velocity, energy density, and intensity in accordance with theory.[10] The addition of careful electrical measurements on the transmitter and receiver provide a means of precisely determining absolute field quantities and the related, forward-radiated, acoustic power.

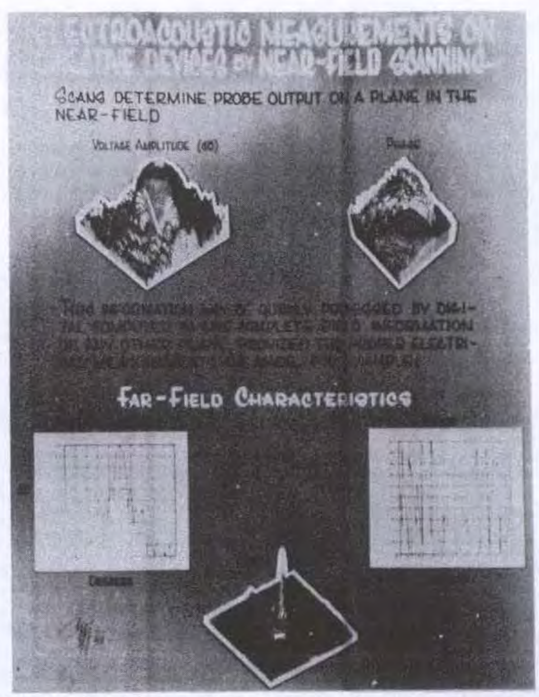

Figure 2. Planar distribution of voltage amplitude and phase measured in the near and far fields.

Calibration of Transducer Power by Measuring Average Near Field Pressure [11]

If a transducer can be found which responds linearly to the total incident force, (not the radiation force) the field amplitude pattern of directive transducers can be measured directly in the near field. This follows from a theory showing that the integrated complex pressure has the same magnitude over parallel planes within the fluid surrounding arbitrary transducers.[10] Further, the magnitude of this force is related by a simple proportionality to the far field amplitude in the direction normal to the planes. Preliminary experimental results, shown in Fig. 3, comparing the far field pattern determined directly and the pattern found from near field measurements, indicate the validity of the theory. The feasibility experiments were accomplished with a 3 mm test transducer (transmitter) separated by about 1.3 cm from a quartz, air-backed, receiving transducer. Care was taken to ensure that all of the power of the transmitter was intercepted by the receiver.

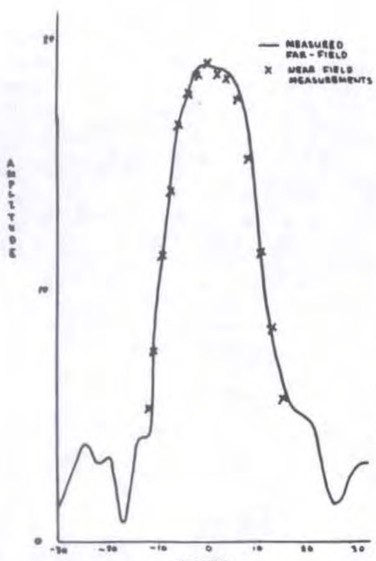

Figure 3. Amplitude distribution of a transducer measured in the far-field compared with the far-field distribution determined from near-field measurements.

A Reproducible Stress Impulse for the Calibration of Acoustic Emission Transducers [12]

In order to interpret acoustic emission signals, the spectral characteristics of the transducer should be known. This is accomplished by applying a reproducible step function of force by breaking a capillary[12] or a lead pencil[13] at a point on, and normal to the plane surface of a semi-infinite isotropic solid and measuring the vertical displacement of the surface. Explicit solutions to this problem first theoretically studied by Lamb[14] have been given.[15] The excellent agreement between theory (Fig. 4) and experiment (Fig. 5) for a transducer located on the same face as the step impulse, but some distance removed, may be seen by comparing Fig. 4 and 5. The electrostatic transducer used to obtain this result, which has a flat wide-band response, then becomes the standard transducer against which is compared the output of test transducers for the same standard seismic event. It becomes very easy, therefore to detect variations in sensitivity and frequency response and to ascertain the effects of changes in clamping force and couplant on response.

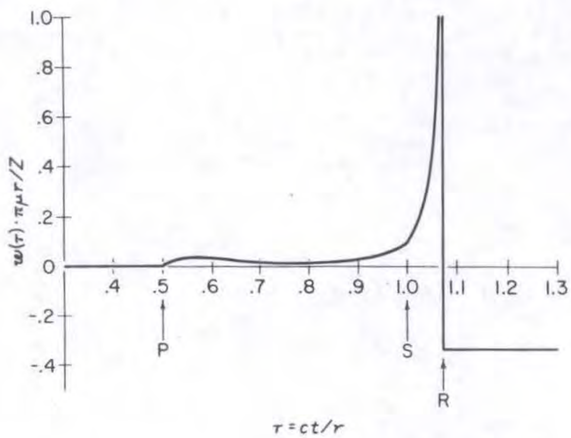

Figure 4. Vertical displacement of surface, W, measured at a distance r from impulse is calculated from an expression of Pekeris[15] for Poisson's ratio equal to 0.25. P, S, and R show arrivals of the longitudinal, shear, and Rayleigh waves, respectively. The speed of the shear wave is c and the shear modulus is μ. Z is the amplitude of the impulse.

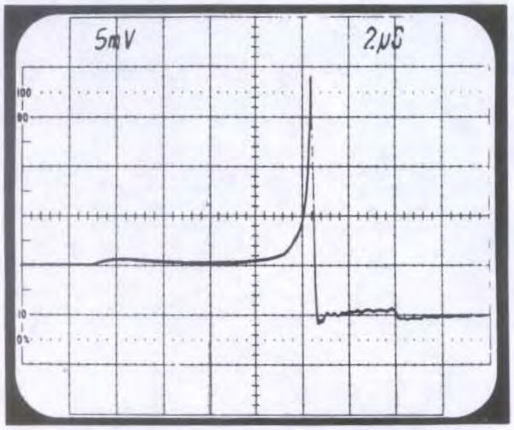

Figure 5. Oscillogram showing result of impulse surface pulse for aluminum-alloy block, Poisson's ratio equals 0.343, 6.3 cm thick and 17.8 cm in diameter. The breaking of a glass capillary 0.15 mm in diameter is the source. Electrostatic transducer is located 5.08 cm from source. Each division or abscissa equals 2μ sec.

Ultrasonic Reference Blocks

Of major concern to the producers and users of ultrasonic reference blocks is the large variability of response from nominally identical standards. In response to this concern, a program to achieve near-term improvements in the reliability of ASTM-type ultrasonic reference blocks (flat-bottom hole) was undertaken. Pulse-echo response of 22 sets of ultrasonic reference blocks of aluminum, steel, and titanium alloys were taken to quantify the variability in response from nominally identical blocks. Techniques for residual stress and microstructural measurements were refined and applied to reference blocks rejected by manufacturers during fabrication in order to evaluate the effect of metallurgical condition on block response. The effects of certain dimensional variables on block response were studied as were the effects of measurement system variables.[16]

As a result of this work a service for the calibration of ASTM E-127-type ultrasonic reference blocks has been established at NBS.[17] A single well-characterized reference block, carefully chosen to be as close as possible to "typical" or "nominal", has been designated as an interim standard against which other blocks can be compared. At present these measurements are primarily comparative due to the lack of a precise mathematical model that describes in a physically meaningful way all the complex interactions that are taking place. However, recent developments in computing the scattering from spheres,[18-20] for example, may make it possible to remove such a limitation. In any case, we plan to examine the role of theory and its implications for standards and calibration procedures.

An Approach to a Rational System of Ultrasonic NDE Standards

In addition to the standards and calibration procedures mentioned here, a great many others have been proposed or are in use. The following statement made in 1962 is still true today: "While it [is] admitted that a number of ultrasonic standards are in use today, none of these has general application; standards either apply to some specific product or material, or they are issued by a particular body or inspection authority and are limited in application." It is clear to standards organizations such as ASTM as well as to the general scientific and user community that the present ultrasonic measurement system is less than ideal and even chaotic in large measure due to an inadequate reference system.

In view of this situation a program sponsored by ARPA has been initiated at NBS to examine in detail the problem of realizing a compatible and traceable system of standards and calibrations for ultrasonic NDE. The steps to be taken include: assessing the current status of ultrasonic NDE standards, determining current and future needs for such standards, and suggesting an approach for realizing them.

No one standard or calibration procedure will be sufficient for the many different types of NDE ultrasonic inspections, different methods, and different parts of the NDE instrument. To deal with such diversity of use and the possibilities that must be considered, a list or criteria for evaluating possible standards and calibrating procedures must be developed. Such criteria include, for example: functional adequacy (will the standards reliably and adequatley accomplish their intended use?), versatility (how many reference standards are needed to carry out calibrations of various instruments for different test objects?), ultimate cost, and compatibility with existing standards. The list, of course, is far from complete but illustrates the complexity of the problem.

In order for such a study to accomplish its objectives, we need the involvement of as many people and groups as possible concerned with these problems. We welcome your inputs to this particular program and to our NDE ultrasonic program.

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